ORAU Team **Dose Reconstruction Project for NIOSH** Internal Dosimetry Coworker Data for Y-12	Document Number: ORAUT-OTIB-0029 Effective Date: 04/05/2005 Revision No.: 00 Controlled Copy No.: _____ Page 1 of 25
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RECORD OF ISSUE/REVISIONS

ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
Draft	01/12/2005	00-A	New technical information bulletin for assignment of Y-12 internal doses based on coworker bioassay data. Initiated by Elizabeth M. Brackett.
Draft	03/08/2005	00-B	Incorporates internal review comments. Initiated by Elizabeth M. Brackett.
Draft	03/17/2005	00-C	Incorporates NIOSH review comments. Initiated by Elizabeth M. Brackett.
04/05/2005	04/05/2005	00	First approved issue. Initiated by Elizabeth M. Brackett.

1.0 PURPOSE

There are instances of energy employees who, for a variety of reasons, were not monitored for internal exposure during the course of their employment at a U.S. Department of Energy (DOE) facility, or whose records of such monitoring are incomplete or unavailable. In such cases, data from coworkers may be used to approximate an individual's possible exposure. This document details the calculation and assignment of intakes based on coworker data from the Y-12 Site.

2.0 OVERVIEW

Analysis of Coworker Bioassay Data for Internal Dose Assignment (ORAU 2004a) describes the general process used for analyzing bioassay data for assigning doses to individuals based on coworker results.

Bioassay results were obtained from the Oak Ridge Institute for Science and Education (ORISE) Center for Epidemiologic Research (CER) Dosimetry Database, which contains uranium urinalysis records from the Y-12 site for 1950 to 1988. ORISE obtained this database from Y-12 for the purpose of conducting an epidemiology study of site workers. The database results are in units of disintegrations per minute (dpm)/day, although original urinalysis results were reported in terms of either mass or activity concentrations, depending on the measurement method. The assumptions used to convert mass results to activity concentrations for inclusion in the database are not known, nor are the assumptions used to normalize spot sample results to 24 hours. A statistical analysis of these data was performed in accordance with ORAU (2004a). The resultant values were input to the IMBA Expert OCAS-Edition computer program, and a fit to the data was performed to obtain intake rates for assigning dose distributions.

3.0 DATA

3.1 SELECTED BIOASSAY DATA

Data were extracted from "Y12 Urinalysis 1950-1988," a Microsoft® Access version of the ORISE/CER Dosimetry Database. Sample dates were taken from the *Date* field and uranium urinalysis results were taken from the field labeled *DPERM_INT* in the database. The latter field contains uranium bioassay results in units of dpm/day. Samples labeled *Control* were excluded from the analysis, as were those with a code of *9* in the *UseFlag* field; documentation provided with the database indicated that the latter meant "do not use data as specified by [Y-12] HP." The reasons for marking particular results are unknown. A review of the database revealed that nearly 20% (85,544 of 479,446) of the results were flagged as not to be used. Of those, 82,892 (97%) had results less than or equal to 0. The excluded results greater than 0 were relatively uniformly distributed among all positive results, and accounted for less than 1% of them (2652 of 299,967).

3.2 ANALYSIS

Because of the large number of sample results, data were analyzed by month. A lognormal distribution was assumed, and the 50th and 84th percentiles were calculated for each month, using the method described in ORAU 2004a. Because there were fewer results in 1950 and 1951, these years were analyzed on annual basis rather than by month. However, the analysis results were not included in the intake modeling because the 50th- and 84th-percentile values were much smaller than later years, and ORAU (2004b) states, "…the technique used prior to May of 1952 may have underestimated the urinary uranium concentrations." January through April of 1952 were included in the modeling because the 50th- and 84th-percentile values were generally larger than subsequent values. Table A-1 shows the statistical analysis results.

4.0 INTAKE MODELING

4.1 ASSUMPTIONS

All results were assumed to be representative of a full day (24 h) of urinary excretion. Each result used in the intake calculation was assumed to be normally distributed, and a uniform absolute error of 1 was applied to all results, thus weighting all results equally. Because of the nature of work at Y-12, a chronic exposure pattern best approximates the true exposure conditions for most workers with a potential for intakes. Intakes were assumed to be via inhalation using a default breathing rate of 1.2 m^3/h and a 5-µm activity median aerodynamic diameter (AMAD) particle size distribution.

The database reported all results as "uranium." Because a variety of enrichments are possible at the Y-12 site, ^{234}U was assumed for the IMBA intake modeling. This does not affect the fitting of the data for intake determination (i.e., the same total intakes would be obtained for any enrichment that was assumed) because all uranium isotopes behave the same biokinetically and the isotopes considered in this analysis have long half-lives relative to the assumed intake period. The ICRP 68 dose coefficients (also referred to as dose conversion factors) for ^{234}U are 7% to 31% larger than those for ^{235}U, ^{236}U, and ^{238}U. Because of the isotopic compositions of the source terms, the ^{234}U dose conversion factor will overestimate doses.

Although there are no bioassay results from before 1950 included in the database, the first intake period was assumed to begin on January 1, 1947. Prior to 1947, the calutron was in operation. There are no bioassay measurements for the period and conditions were likely quite different than at later times on the site, so this period was not included in the modeling. The *Technical Basis Document for the Y-12 National Security Complex – Site Description* (ORAU 2003) states, "Y-12 was shut down in Dec. 1946 and employment was cut drastically," in reference to the calutron and associated uranium isotope separation programs. Primary operations from 1947 to 1951 consisted of salvage, recovery, and recycle operations, with uranium preparation and machining beginning in 1949. It was therefore assumed that exposure conditions beginning in 1947 would have been similar to those in the early 1950s.

4.2 BIOASSAY FITTING

The IMBA Expert OCAS-Edition computer program was used to fit the bioassay results to a series of inhalation intakes. IMBA allows the input of 200 urine sample results, which is insufficient to include all of the Y-12 monthly results. However, this can be expanded to 400 results by using the user-defined bioassay function and applying all of the urine parameters to this function. Data from January 1952 through December 1988 were fit as a series of chronic intakes.

The initial intake assumptions were based on periods that coincided with major operations on the site. The years 1947 to 1951 had very specific operations and were therefore modeled as one intake period. However, the bioassay data had some distinct patterns, so the intake dates were adjusted to obtain a better approximation of the data. There appeared to be low-level chronic intakes of uranium throughout long periods, with briefer, larger intakes superimposed on them. To model this pattern, three long-term chronic exposures were assumed to cover 1947 through 1988. Five shorter chronic exposures were modeled on top of the early period to account for the intermittent rises in the urine results.

Because the uranium isotopes present at Y-12 have very long half-lives and the material is retained in the body for long periods, excretion results are not independent. For example, an intake in the early 1950s could contribute to urinary excretion in the 1980s and later. To avoid potential underestimation of intakes for people who worked at Y-12 for relatively short periods, each intake was fit independently, using only the bioassay results from the single intake period. This will likely result

in an overestimate of intakes, particularly for assumed type S exposures extending through multiple assumed intake periods.

4.3 MATERIAL TYPES

Section 5.1.1 of ORAU (2004b) notes, "while the exceptional cases with unusually protracted lung clearance are important, it is more important to note that, for the vast majority of individuals, lung clearance took place in approximate accordance with the ICRP Publication 2 "Insoluble" model, which fits within the current "Type M" framework." Because there have been cases of very insoluble material noted on the site, both types M and S were evaluated.

All of the bioassay results were entered into IMBA, and are therefore displayed in the figures (Attachment A). However, as described in Section 4.2, each period was fit separately so only the results within the intake period were selected for use in fitting each period. Excluded results are shown in red in the figures.

4.3.1 Type M

Uranium urine results were fit using a type M material. Figures A-1 to A-8 show the individual fits to the 50th-percentile values. The same intake periods were applied to the 84th-percentile values because the values followed a similar pattern; results of the individual fits are not shown here but they fit reasonably well. Table 4-1 summarizes the intake periods and corresponding intake rates for the 50th- and 84th-percentiles.

Figure A-9 shows a representation of the 50th-percentile predicted values from all intakes, and Figure A-10 shows the 84th-percentile predictions. These depict the expected excretion rates from an individual exposed for all the periods at the 50th and 84th percentile intake rates, respectively, specified in Table 4-1. The geometric standard deviations (GSDs) were determined by dividing the 84th percentile intake rates by the 50th percentile intake rates..

4.3.2 Type S

The intake periods used in the type M fits were also applied to the type S material fits. Figures A-11 to A-18 show the individual fits for the 50th-percentile values. Table 4-2 summarizes the intake rates for the 50th- and 84th-percentile values. The GSDs were determined as noted for the type M intake rates.

Figures A-19 and A-20 show the 50th- and 84th-percentiles' predicted excretion rates, respectively, from all type S intakes.

Table 4-1. Type M uranium intake periods and rates.

		Uranium intake rate (dpm/day)		
Start date	Stop date	50th percentile	84th percentile	GSD
1/1/1947	2/28/1978	169.34	598.93	3.54
1/1/1947	4/30/1952	354.59	1,154.9	3.26
8/1/1953	11/30/1953	547.22	1,963.1	3.59
11/1/1956	2/28/1959	226.90	825.31	3.64
6/1/1961	12/31/1962	248.68	866.81	3.49
10/1/1968	12/31/1972	160.67	601.60	3.74
3/1/1978	9/30/1984	80.03	355.93	4.45
10/1/1984	12/31/1988	44.203	223.85	5.06

Figure 4-9. Predicted (type M, 5 µm) uranium urinary excretion from eight independent intakes, 50th percentile, 1952-1988.

Table 4-2. Type S uranium intake periods and rates.

Start date	Stop date	Uranium intake rate (dpm/day)		GSD
		50th percentile	84th percentile	
1/1/1947	2/28/1978	1,844.4	6,544.2	3.55
1/1/1947	4/30/1952	5,210.4	16,970	3.26
8/1/1953	11/30/1953	17,983	64,559	3.59
11/1/1956	2/28/1959	5,694.6	20,560	3.61
6/1/1961	12/31/1962	6,849.4	23,632	3.45
10/1/1968	12/31/1972	3,290.3	12,415	3.77
3/1/1978	9/30/1984	1,280.3	5,802.9	4.53
10/1/1984	12/31/1988	884.85	4,340.6	4.91

5.0 ASSIGNMENT OF INTAKES AND DOSES

5.1 INTAKE RATE SUMMARY

Several intake periods overlapped, so they were combined to make 12 distinct intake periods, with a single intake rate and associated GSD for each. For 1947 through February 1978, all GSDs were within 10% of each other, so the largest GSD for the period was assigned to all intake rates for simplicity. Table 5-1 summarizes the 12 intake periods. Note that these are equivalent to the 8 intake periods specified in Table 4-1, but provide a chronological layout of the changing intake rates over time.

5.2 CONTRIBUTION FROM CONTAMINANTS IN RECYCLED URANIUM

Throughout the DOE complex, spent fuel from fission reactors has been processed to recover uranium for recycling. Because the uranium streams at Y-12 could have contained recycled uranium, the dose from the added constituents, including plutonium, ^{237}Np, and ^{99}Tc, must be included. See ORAU (2004b) for information about intake values relative to the uranium intake amounts.

5.3 DOSE ASSIGNMENT

Doses to be assigned to individuals are calculated from the 50th-percentile intake rates; the material type resulting in the largest probability of causation is selected. A comparison of the intake rates shows that the type S assumption is more than an order of magnitude larger than the type M intake for all periods. However, because the type S material remains in the lungs for an extended period while the type M material is transferred to the systemic organs, it is necessary to compare the annual doses on a case-by-case basis to determine which will deliver the larger dose to the organ of interest. Recycled uranium contaminants, when appropriate for the period, will also factor in to this comparison.

The lognormal distribution is selected in the Interactive RadioEpidemiological Program (IREP), with the calculated dose entered as Parameter 1 and the associated GSD as Parameter 2. The GSD is associated with the intake, so it is applied to all annual doses determined from the intake period.

Table 5-1. Combined uranium intake periods and rates.

Start date	Stop date	Type M Intake Rate (dpm/day)			Type S Intake Rate (dpm/day)		
		50th Percentile	84th Percentile	GSD	50th Percentile	84th Percentile	GSD
1/1/1947	4/30/1952	523.93	1753.83	3.74	7054.4	23514.2	3.77
5/1/1952	7/31/1953	169.34	598.93	3.74	1844.4	6544.2	3.77
8/1/1953	11/30/1953	716.56	2562.03	3.74	19827	71103.2	3.77
12/1/1953	10/31/1956	169.34	598.93	3.74	1844.4	6544.2	3.77
11/1/1956	2/28/1959	396.24	1424.23	3.74	7539	27104.2	3.77
3/1/1959	5/31/1961	169.34	598.93	3.74	1844.4	6544.2	3.77
6/1/1961	12/31/1962	418.02	1465.73	3.74	8693.4	30176.2	3.77
1/1/1963	9/30/1968	169.34	598.93	3.74	1844.4	6544.2	3.77
10/1/1968	12/31/1972	330.01	1200.53	3.74	5134.4	18959.2	3.77
1/1/1973	2/28/1978	169.34	598.93	3.74	1844.4	6544.2	3.77
3/1/1978	9/30/1984	80.03	355.93	4.45	1280.3	5802.9	4.53
10/1/1984	12/31/1988	44.20	223.85	5.06	884.85	4340.6	4.91

REFERENCES

ICRP (International Commission on Radiological Protection), 1959, *Report of ICRP Committee II on Permissible Dose for Internal Radiation*, Publication 2, Pergamon Press, Oxford, England.

ORAU (Oak Ridge Associated Universities), 2003, *Technical Basis Document for the Y-12 National Security Complex – Site Description*, ORAUT-TKBS-0014-02, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004a, *Analysis of Coworker Bioassay Data for Internal Dose Assignment*, ORAUT-OTIB-0019, Oak Ridge, Tennessee.

ORAU (Oak Ridge Associated Universities), 2004b, *Technical Basis Document for the Y-12 National Security Complex – Occupational Internal Dose*, ORAUT-TKBS-0014-5, Oak Ridge, Tennessee.

Attachment A

Table A-1: Summary of monthly uranium 24-hour urinary excretion rate analyses, 1952-1988.

Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)
1/15/1952	21.16	64.00	3/15/1956	14.02	42.59	5/15/1960	11.19	38.09
2/14/1952	24.92	84.51	4/15/1956	16.45	46.84	6/15/1960	9.88	37.26
3/15/1952	23.86	88.16	5/15/1956	15.73	47.57	7/15/1960	10.51	37.64
4/15/1952	25.49	74.15	6/15/1956	13.79	40.67	8/15/1960	12.76	51.09
5/15/1952	21.15	51.31	7/15/1956	13.82	41.39	9/14/1960	9.45	32.20
6/15/1952	18.06	47.31	8/15/1956	13.39	41.44	10/14/1960	8.93	32.44
7/15/1952	14.13	41.90	9/14/1956	14.11	38.28	11/14/1960	9.85	35.50
8/15/1952	11.25	33.06	10/14/1956	11.10	32.33	12/14/1960	7.60	27.11
9/14/1952	13.70	35.97	11/14/1956	4.72	15.14	1/14/1961	7.53	32.63
11/14/1952	16.68	46.41	1/14/1957	9.42	28.04	3/16/1961	9.36	37.96
12/14/1952	14.29	37.68	2/13/1957	10.20	38.81	4/15/1961	8.94	32.38
1/14/1953	12.61	37.15	3/16/1957	11.04	40.78	5/16/1961	7.46	26.83
2/13/1953	10.51	32.28	4/15/1957	10.79	33.80	6/15/1961	9.17	32.46
3/16/1953	9.18	26.40	5/16/1957	10.48	42.11	7/15/1961	11.04	38.61
4/15/1953	10.34	32.25	6/15/1957	9.44	34.06	8/15/1961	5.80	23.46
5/16/1953	10.43	33.25	7/15/1957	8.46	28.63	9/14/1961	12.96	54.55
6/15/1953	9.81	34.90	8/15/1957	10.56	35.75	10/15/1961	8.55	29.21
7/15/1953	11.13	40.08	9/14/1957	7.51	24.91	11/14/1961	7.46	28.68
9/14/1953	19.53	63.39	11/14/1957	13.03	44.83	1/14/1962	11.93	48.51
10/15/1953	32.43	110.13	12/15/1957	11.29	37.96	2/13/1962	14.10	55.59
11/14/1953	26.65	88.11	1/14/1958	8.36	30.87	3/16/1962	22.09	81.26
12/15/1953	18.47	57.43	2/13/1958	13.64	53.23	4/15/1962	16.35	63.01
1/14/1954	19.45	84.37	3/16/1958	16.24	59.24	5/16/1962	10.69	39.93
2/13/1954	16.06	74.20	4/15/1958	13.30	52.29	6/15/1962	19.41	71.41
3/16/1954	19.50	74.74	5/16/1958	12.71	56.35	7/16/1962	13.57	52.64
4/15/1954	22.04	78.72	6/15/1958	13.70	77.06	8/15/1962	12.66	58.77
5/16/1954	22.85	77.01	7/16/1958	17.44	79.66	9/15/1962	19.24	72.07
7/16/1954	22.06	83.01	9/15/1958	19.19	86.52	11/14/1962	16.91	65.36
8/15/1954	15.39	63.49	10/15/1958	15.21	58.52	12/15/1962	22.87	97.50
9/15/1954	8.47	28.08	11/14/1958	21.01	73.93	1/14/1963	16.80	64.65
10/15/1954	11.58	50.14	12/15/1958	22.76	80.61	2/14/1963	14.35	65.28
11/14/1954	22.02	91.14	1/14/1959	20.74	77.72	3/16/1963	17.58	70.17
12/15/1954	14.85	45.87	2/14/1959	24.90	90.03	4/16/1963	13.52	46.46
1/14/1955	7.36	25.15	3/16/1959	18.71	60.78	5/16/1963	12.56	44.00
2/14/1955	5.62	19.81	4/16/1959	19.72	66.84	6/15/1963	14.88	56.00
3/16/1955	13.71	39.83	5/16/1959	17.44	56.57	7/16/1963	13.40	36.41
5/16/1955	13.27	37.94	7/16/1959	16.69	57.44	9/15/1963	13.48	44.18
6/15/1955	15.71	47.63	8/15/1959	12.79	40.15	10/15/1963	11.65	38.88
7/16/1955	13.10	36.57	9/15/1959	13.66	43.44	11/15/1963	9.50	26.83
8/15/1955	13.85	42.78	10/15/1959	11.53	40.87	12/15/1963	7.73	26.04
9/15/1955	17.10	55.19	11/15/1959	14.86	53.07	1/15/1964	8.00	28.09
10/15/1955	16.87	51.49	12/15/1959	16.04	56.60	2/14/1964	7.96	24.14
11/15/1955	12.99	39.56	1/15/1960	13.87	43.69	3/15/1964	10.27	32.95
12/15/1955	15.34	45.01	2/14/1960	13.36	46.00	4/15/1964	4.60	15.35
1/15/1956	14.50	47.71	3/15/1960	9.31	34.17	5/15/1964	3.58	10.53

Table A-1 (Continued): Summary of monthly uranium 24-hour urinary excretion rate analyses, 1952-1988.

Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)
5/15/1964	3.58	10.53	7/15/1968	5.20	23.25	9/14/1972	18.14	54.91
7/15/1964	5.66	18.62	9/14/1968	5.48	26.46	11/14/1972	12.00	42.03
8/15/1964	4.65	14.20	10/14/1968	3.86	16.16	12/14/1972	20.42	61.50
9/14/1964	4.62	12.61	11/14/1968	5.90	23.37	1/14/1973	15.63	41.34
10/14/1964	3.43	9.95	12/14/1968	9.71	32.61	2/13/1973	15.79	57.05
11/14/1964	3.26	10.78	1/14/1969	8.43	41.12	3/16/1973	15.71	49.06
12/14/1964	7.72	21.81	2/13/1969	5.02	20.69	4/15/1973	16.20	48.06
1/14/1965	4.70	14.91	3/16/1969	5.65	27.79	5/16/1973	14.46	47.02
2/13/1965	3.99	12.84	4/15/1969	7.61	36.08	6/15/1973	15.04	56.06
3/16/1965	6.81	23.26	5/16/1969	5.22	24.92	7/15/1973	14.38	43.07
5/16/1965	6.70	23.60	7/15/1969	7.37	29.64	9/14/1973	12.97	56.63
6/15/1965	9.45	31.48	8/15/1969	6.62	28.37	10/15/1973	12.31	40.96
7/15/1965	5.64	18.05	9/14/1969	4.70	17.88	11/14/1973	10.62	29.86
8/15/1965	6.41	23.41	10/15/1969	6.60	25.36	12/15/1973	14.20	46.52
9/14/1965	2.74	11.57	11/14/1969	7.06	22.98	1/14/1974	12.16	38.96
10/15/1965	4.91	18.07	12/15/1969	7.71	30.81	2/13/1974	11.16	34.34
11/14/1965	3.44	12.05	1/14/1970	9.84	40.81	3/16/1974	20.33	56.38
12/15/1965	9.85	37.35	2/13/1970	8.33	28.27	4/15/1974	12.99	40.27
1/14/1966	4.44	19.14	3/16/1970	7.85	29.62	5/16/1974	9.14	22.89
3/16/1966	10.17	42.75	5/16/1970	4.93	18.99	7/16/1974	7.54	20.57
4/15/1966	10.75	48.01	6/15/1970	11.17	44.73	8/15/1974	8.44	24.96
5/16/1966	5.04	16.99	7/16/1970	8.88	38.05	9/15/1974	8.77	24.28
6/15/1966	6.32	26.44	8/15/1970	8.76	42.72	10/15/1974	14.19	137.02
7/16/1966	8.70	39.61	9/15/1970	11.59	55.40	11/14/1974	9.16	53.77
8/15/1966	5.01	18.31	10/15/1970	9.81	34.23	12/15/1974	8.11	35.07
9/15/1966	8.86	40.76	11/14/1970	13.10	51.16	1/14/1975	8.93	37.19
10/15/1966	15.88	71.36	12/15/1970	17.14	67.22	2/14/1975	11.49	44.05
11/14/1966	8.68	32.40	1/14/1971	4.41	18.55	3/16/1975	16.92	57.92
1/14/1967	6.79	33.34	3/16/1971	12.76	50.18	5/16/1975	11.74	39.05
2/14/1967	5.80	25.69	4/16/1971	9.52	39.99	6/15/1975	10.66	33.40
3/16/1967	8.35	49.25	5/16/1971	5.87	21.42	7/16/1975	11.04	38.53
4/16/1967	10.81	56.82	6/15/1971	10.37	41.16	8/15/1975	11.07	32.85
5/16/1967	3.25	18.88	7/16/1971	4.67	19.49	9/15/1975	8.90	31.58
6/15/1967	6.51	25.46	8/15/1971	10.74	47.49	10/15/1975	11.92	36.58
7/16/1967	5.49	35.82	9/15/1971	13.95	62.06	11/15/1975	9.18	32.82
8/15/1967	7.30	40.93	10/15/1971	8.25	32.76	12/15/1975	12.88	40.99
9/15/1967	4.42	19.34	11/15/1971	8.24	29.09	1/15/1976	9.97	30.51
11/15/1967	5.01	20.71	1/15/1972	11.54	44.77	3/15/1976	9.19	28.35
12/15/1967	6.06	33.53	2/14/1972	12.20	43.92	4/15/1976	8.65	27.03
1/15/1968	6.50	28.54	3/15/1972	15.64	56.16	5/15/1976	8.30	24.08
2/14/1968	10.15	41.09	4/15/1972	12.09	47.06	6/15/1976	8.24	23.91
3/15/1968	8.10	39.56	5/15/1972	12.64	50.99	7/15/1976	3.82	12.47
4/15/1968	7.07	43.78	6/15/1972	13.68	34.90	8/15/1976	6.51	18.64
5/15/1968	11.07	53.86	7/15/1972	18.95	70.38	9/14/1976	5.39	14.99
6/15/1968	7.05	29.75	8/15/1972	20.33	67.87	10/14/1976	9.50	26.06

Table A-1 (Continued): Summary of monthly uranium 24-hour urinary excretion rate analyses, 1952-1988.

Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)	Effective Sample Date	50th percentile (dpm/d)	84th percentile (dpm/d)
11/14/1976	13.24	40.32	1/12/1981	6.78	27.85	4/14/1985	1.67	8.60
1/14/1977	13.97	44.66	3/14/1981	6.20	20.98	6/14/1985	0.76	5.03
2/13/1977	13.41	41.70	4/14/1981	4.81	19.11	7/15/1985	1.91	8.85
3/16/1977	12.91	40.62	5/14/1981	3.66	15.89	8/14/1985	1.97	7.66
4/15/1977	8.86	24.33	6/14/1981	5.97	21.83	9/14/1985	2.76	11.77
5/16/1977	8.39	22.81	7/14/1981	6.47	31.68	10/14/1985	1.82	6.05
6/15/1977	9.62	31.33	8/13/1981	4.89	16.79	11/13/1985	1.53	6.04
7/15/1977	7.46	28.02	9/13/1981	6.13	22.23	12/14/1985	2.71	11.36
8/15/1977	9.29	25.59	10/13/1981	5.14	21.72	1/13/1986	2.79	11.56
9/14/1977	11.22	54.94	11/13/1981	4.35	18.28	2/13/1986	1.10	5.61
11/14/1977	10.75	47.78	1/13/1982	4.53	18.34	4/15/1986	1.35	5.24
12/15/1977	9.31	35.70	2/12/1982	4.13	15.44	5/15/1986	1.12	5.13
1/14/1978	9.28	35.13	3/15/1982	5.01	18.71	6/15/1986	1.63	7.52
2/13/1978	9.82	29.72	4/14/1982	5.72	32.11	7/15/1986	2.42	11.67
3/15/1978	4.34	13.13	5/14/1982	6.89	24.15	8/14/1986	2.54	10.13
4/14/1978	8.07	26.41	6/14/1982	5.47	20.50	9/14/1986	1.79	8.35
5/14/1978	5.53	18.15	7/14/1982	4.66	17.11	10/14/1986	0.95	4.22
6/14/1978	4.73	14.79	8/14/1982	6.48	31.75	11/14/1986	2.60	11.31
7/14/1978	6.58	20.43	9/13/1982	2.92	10.86	12/14/1986	1.17	6.57
9/13/1978	7.02	22.71	11/13/1982	3.24	12.97	2/13/1987	9.62	57.02
10/14/1978	7.51	22.85	12/13/1982	2.94	13.34	3/15/1987	5.04	18.90
11/13/1978	6.81	24.14	1/13/1983	3.67	15.42	4/15/1987	2.50	13.62
12/13/1978	4.93	15.71	2/12/1983	5.93	23.87	5/15/1987	2.43	11.68
1/13/1979	5.48	22.99	3/15/1983	5.51	26.40	6/15/1987	2.20	19.91
2/12/1979	5.73	24.87	4/14/1983	4.51	17.99	7/15/1987	8.16	46.96
3/15/1979	7.50	55.07	5/15/1983	4.83	19.89	8/15/1987	13.59	70.44
4/14/1979	4.12	20.11	6/14/1983	2.99	12.46	9/14/1987	4.01	19.30
5/15/1979	5.45	26.64	7/15/1983	2.74	9.92	10/15/1987	0.44	2.13
7/15/1979	6.15	26.52	10/15/1983	3.36	16.08	12/14/1987	2.13	11.13
8/14/1979	2.81	8.47	11/14/1983	2.69	14.10	1/14/1988	2.19	14.84
9/13/1979	7.52	23.80	12/14/1983	2.08	8.98	2/13/1988	2.37	10.64
10/14/1979	6.69	21.68	1/14/1984	2.72	11.00	3/15/1988	4.62	24.43
11/13/1979	5.68	16.34	2/13/1984	2.59	14.01	4/14/1988	4.03	26.36
12/14/1979	10.15	28.45	3/15/1984	4.20	20.09	5/15/1988	1.52	7.09
1/13/1980	5.43	19.51	4/14/1984	4.14	21.85	6/14/1988	2.05	13.32
2/13/1980	5.39	18.48	5/15/1984	3.51	15.94	7/14/1988	4.03	19.34
3/14/1980	9.96	31.50	6/14/1984	3.42	15.07	8/14/1988	2.96	17.83
5/14/1980	6.08	23.84	8/14/1984	2.96	17.55	10/14/1988	0.75	3.70
6/13/1980	7.52	24.86	9/13/1984	3.97	20.81	11/13/1988	2.18	10.51
7/14/1980	4.43	13.44	10/14/1984	6.23	26.17	12/14/1988	3.69	13.94
8/13/1980	4.33	14.91	11/13/1984	2.68	8.13			
9/13/1980	5.59	16.59	12/14/1984	4.62	20.08			
10/13/1980	8.80	27.70	1/13/1985	2.93	12.00			
11/13/1980	3.70	14.66	2/13/1985	1.93	8.23			
12/13/1980	6.65	26.31	3/15/1985	4.45	31.70			

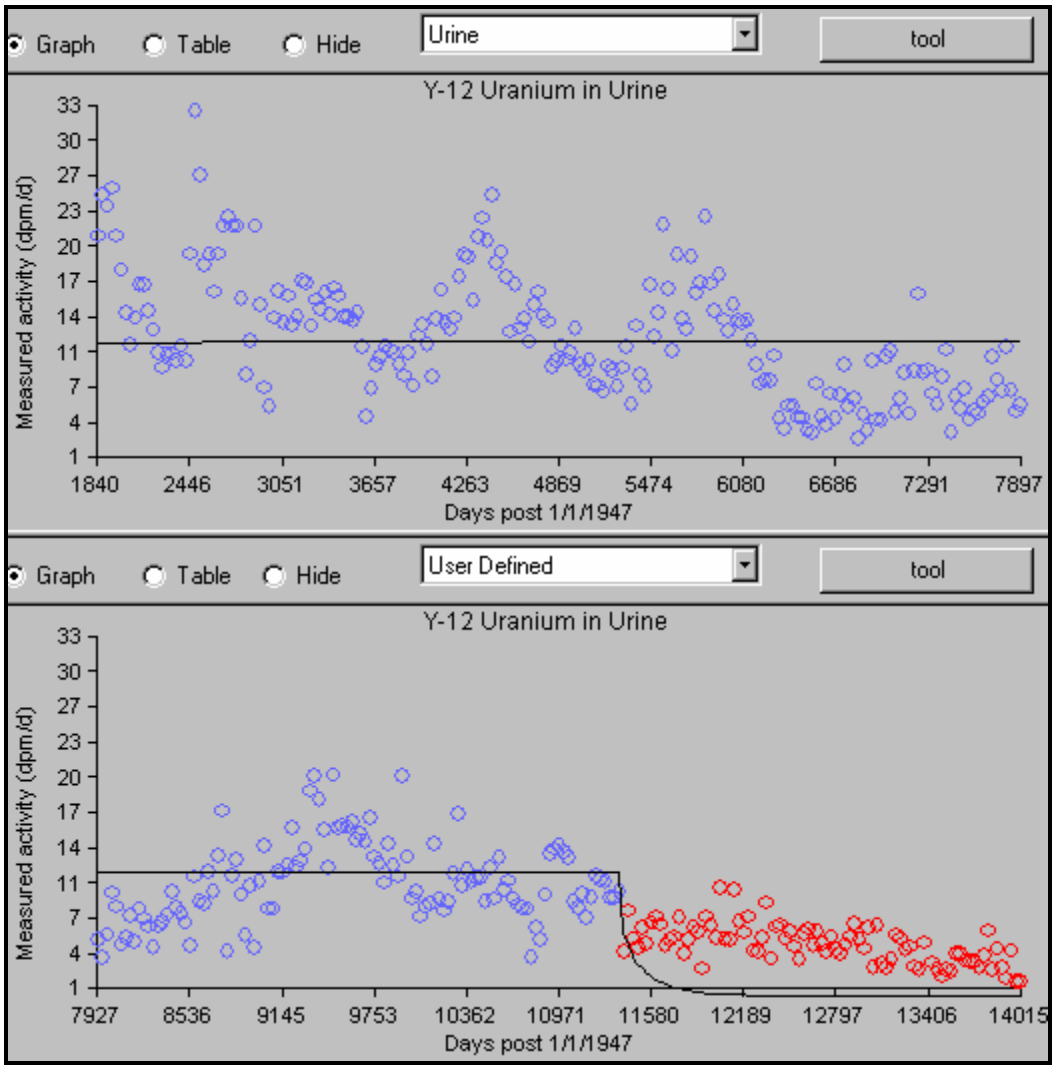


Figure A-1. Assumed uranium intake, 1/1/47 to 2/28/78, 50th-percentile results, type M.

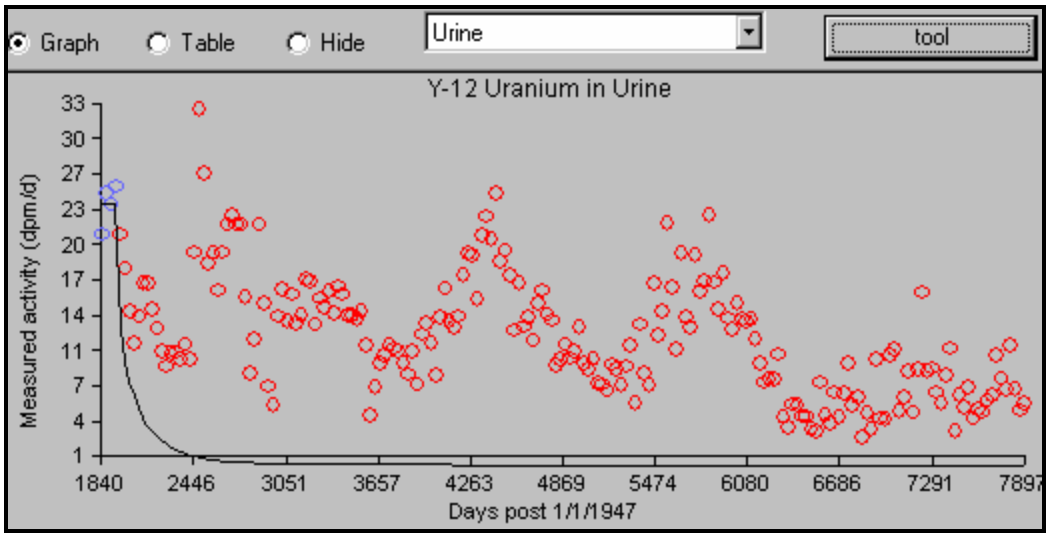


Figure A-2. Assumed uranium intake, 1/1/47 to 4/30/52, 50th-percentile results, type M.

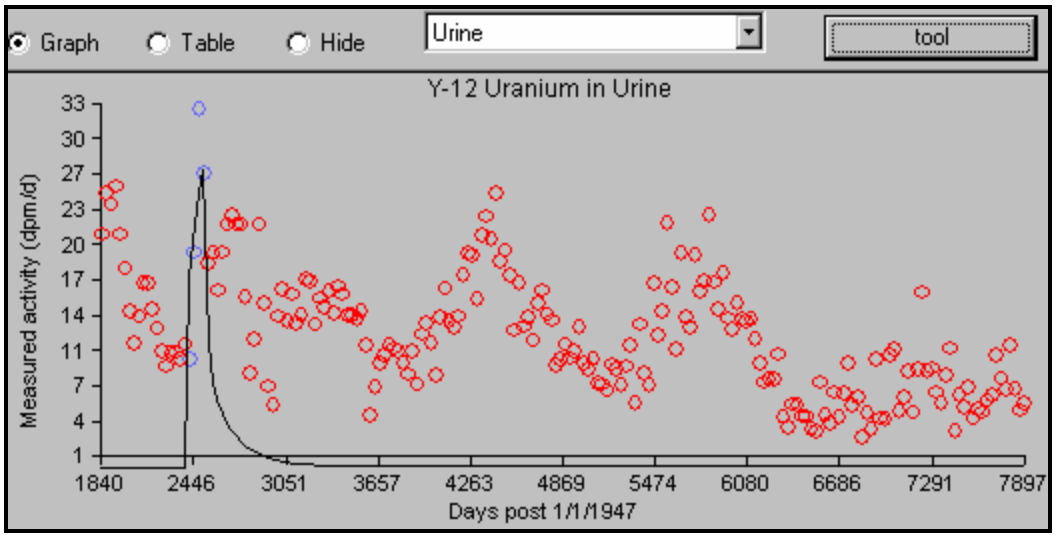


Figure A-3. Assumed uranium intake, 8/1/53 to 11/30/53, 50th-percentile results, type M.

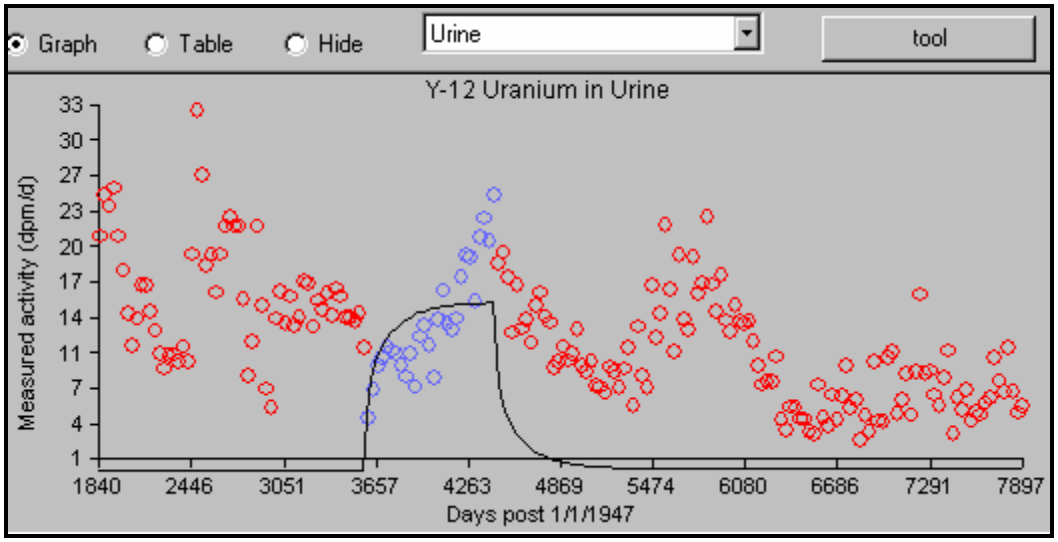


Figure A-4. Assumed uranium intake, 11/1/56 to 2/28/59, 50th-percentile results, type M.

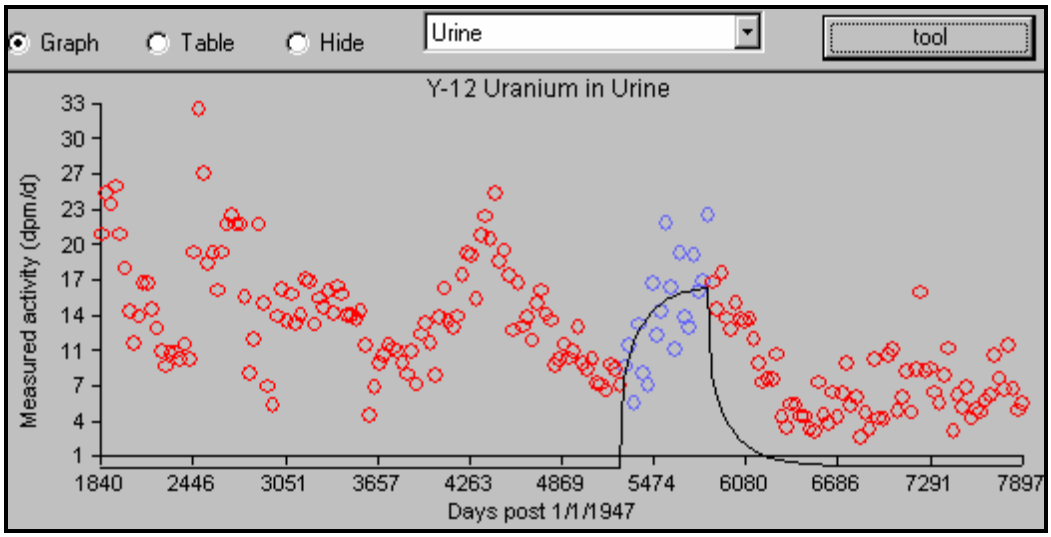


Figure A-5. Assumed uranium intake, 6/1/61 to 12/31/62, 50th-percentile results, type M.

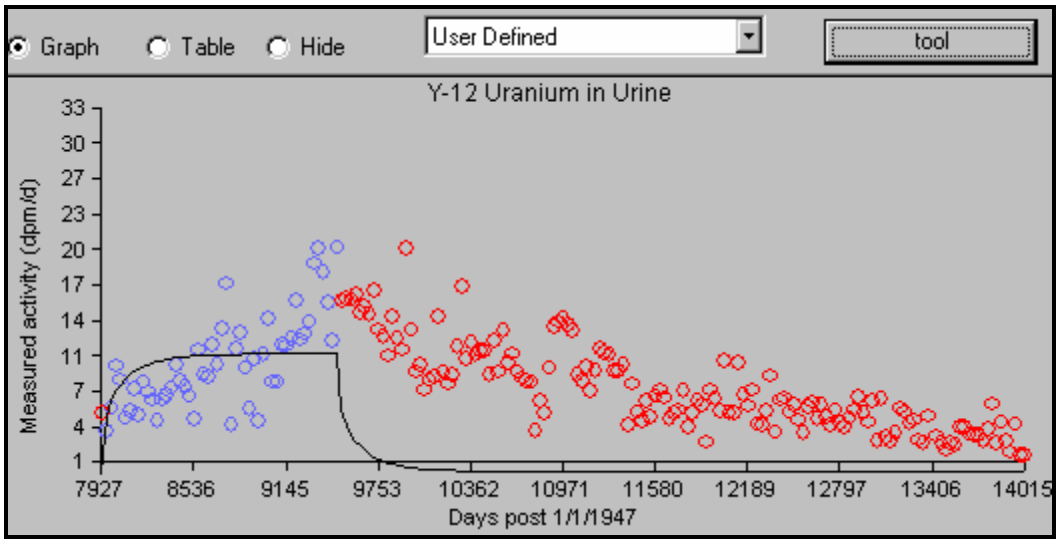


Figure A-6. Assumed uranium intake, 10/1/68 to 12/31/72, 50th-percentile results, type M.

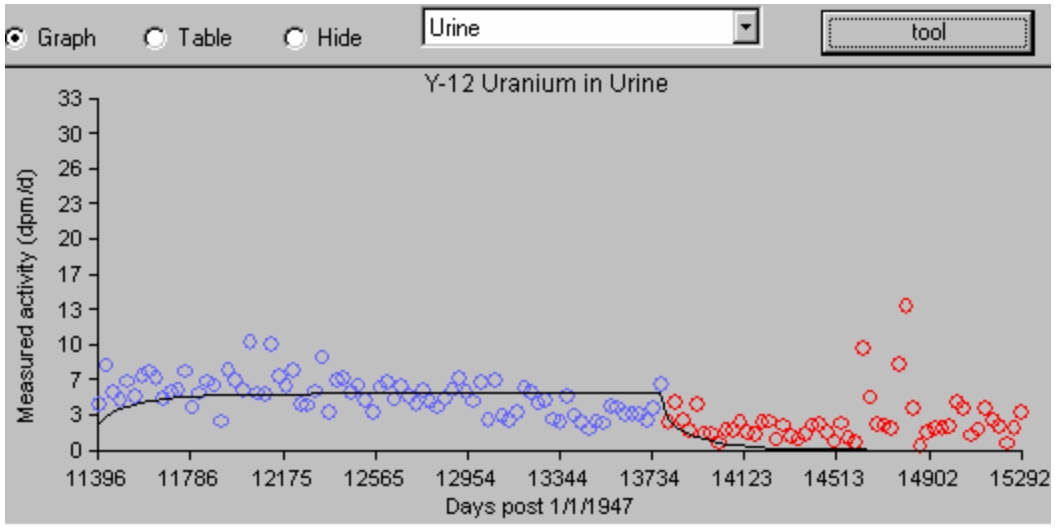


Figure A-7. Assumed uranium intake, 3/1/78 to 9/30/84, 50th-percentile results, type M.

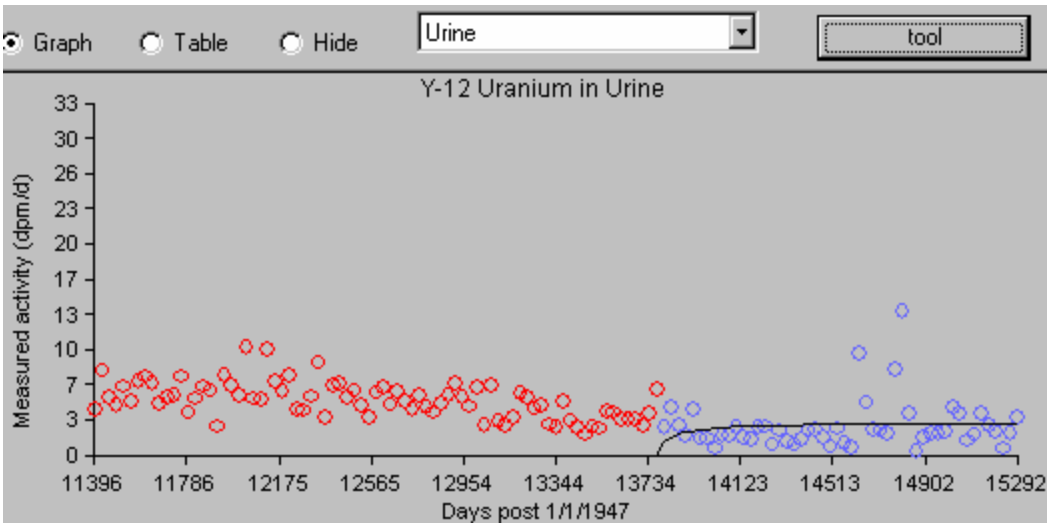
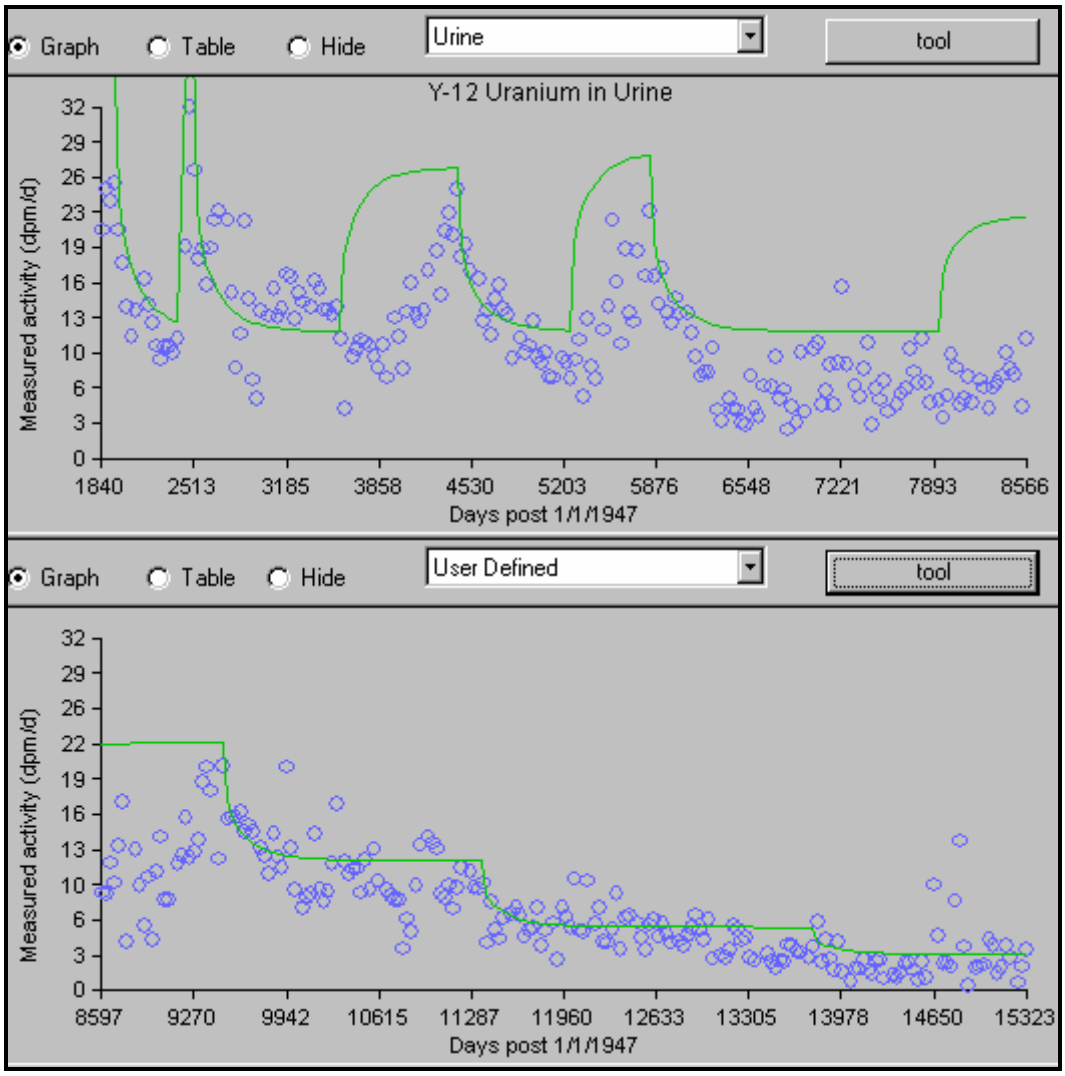


Figure A-8. Assumed uranium intake, 10/1/84 to 12/31/88, 50th-percentile results, type M.



O monthly bioassay value (50th percentile)

predicted excretion

Figure A-9. Predicted (type M, 5 µm) uranium urinary excretion from eight independent intakes, 50th percentile, 1952-1988.

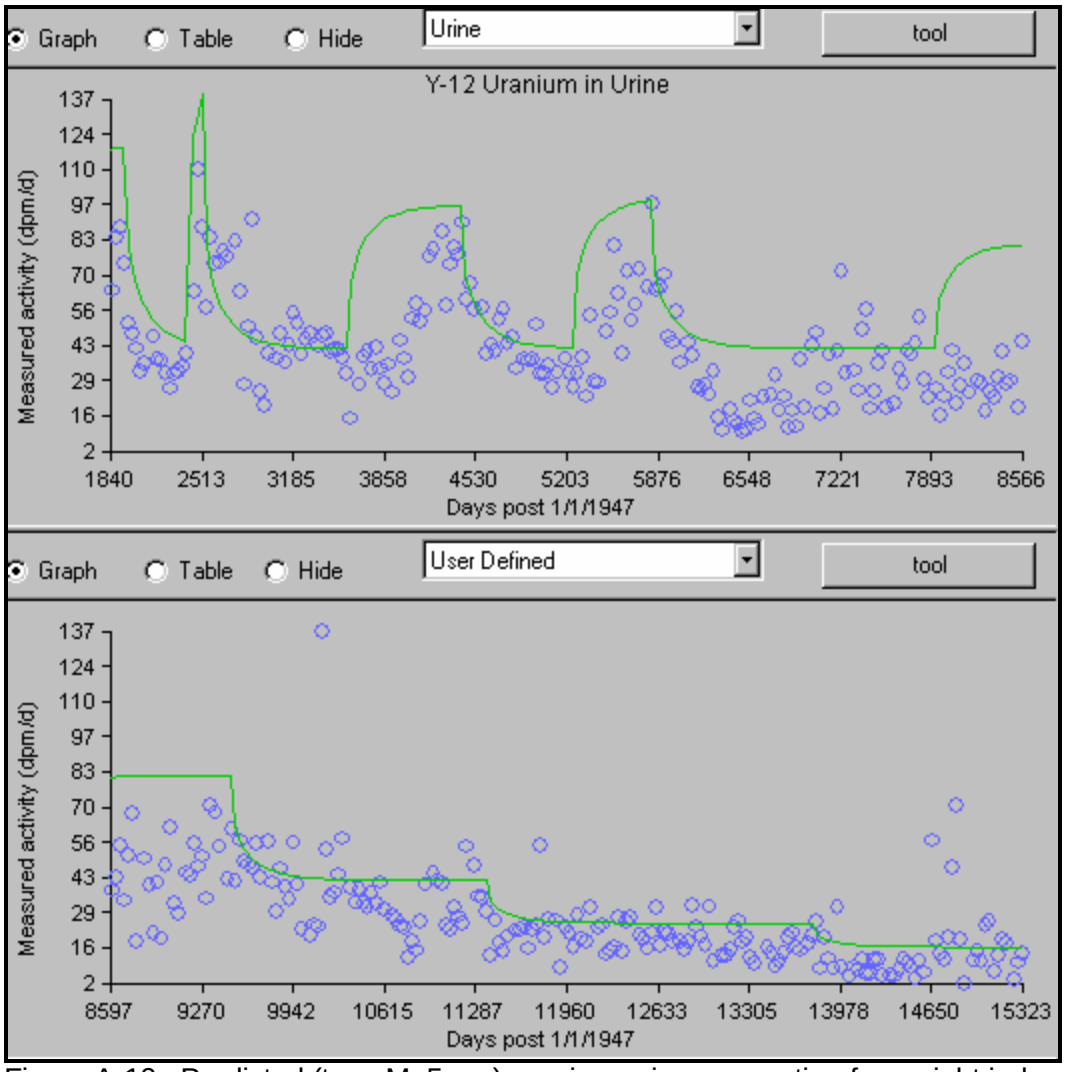


Figure A-10. Predicted (type M, 5 µm) uranium urinary excretion from eight independent intakes, 84th percentile, 1952-1988.

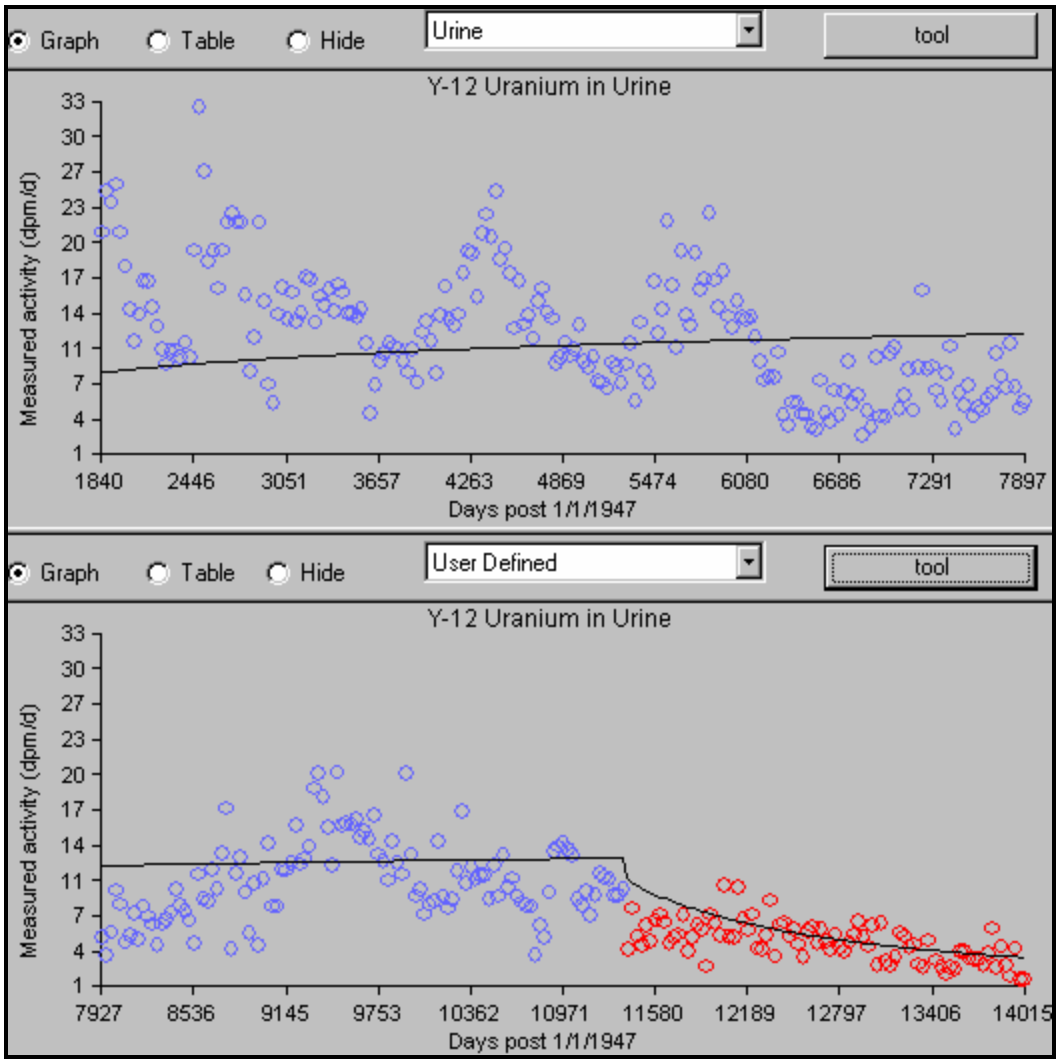


Figure A-11. Assumed uranium intake, 1/1/47 to 2/28/78, 50th-percentile results, type S.

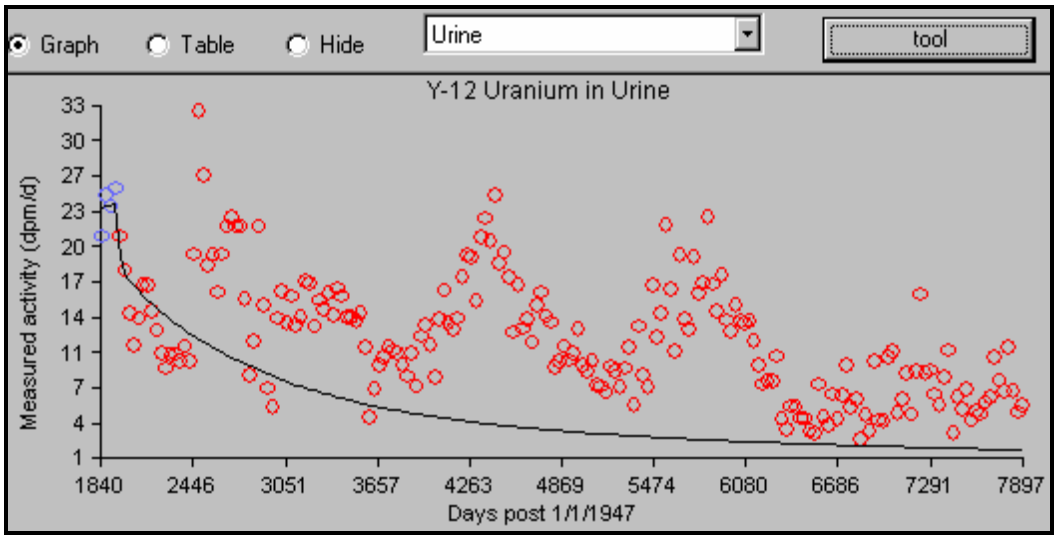


Figure A-12. Assumed uranium intake, 1/1/47 to 4/30/52, 50th-percentile results, type S.

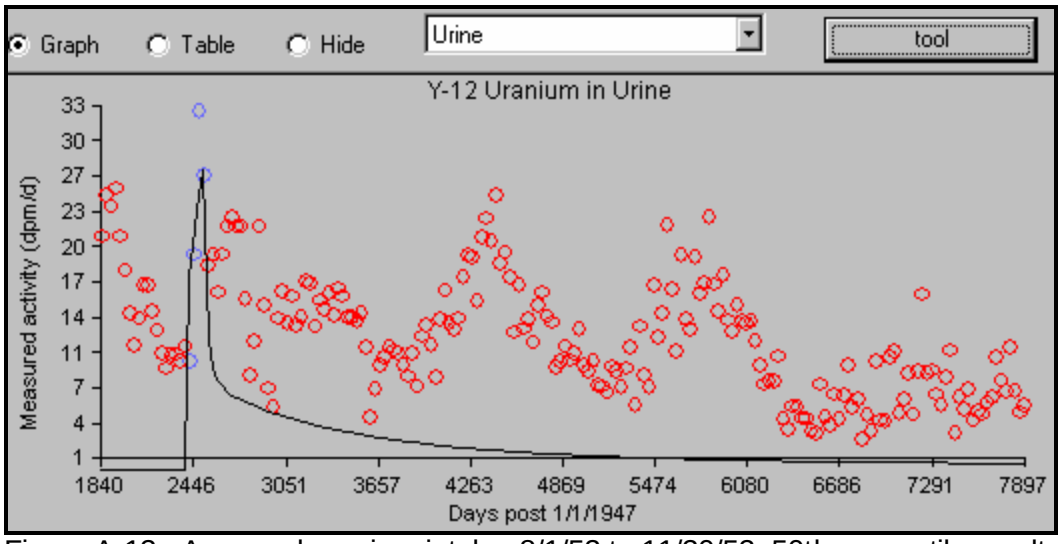


Figure A-13. Assumed uranium intake, 8/1/53 to 11/30/53, 50th-percentile results, type S.

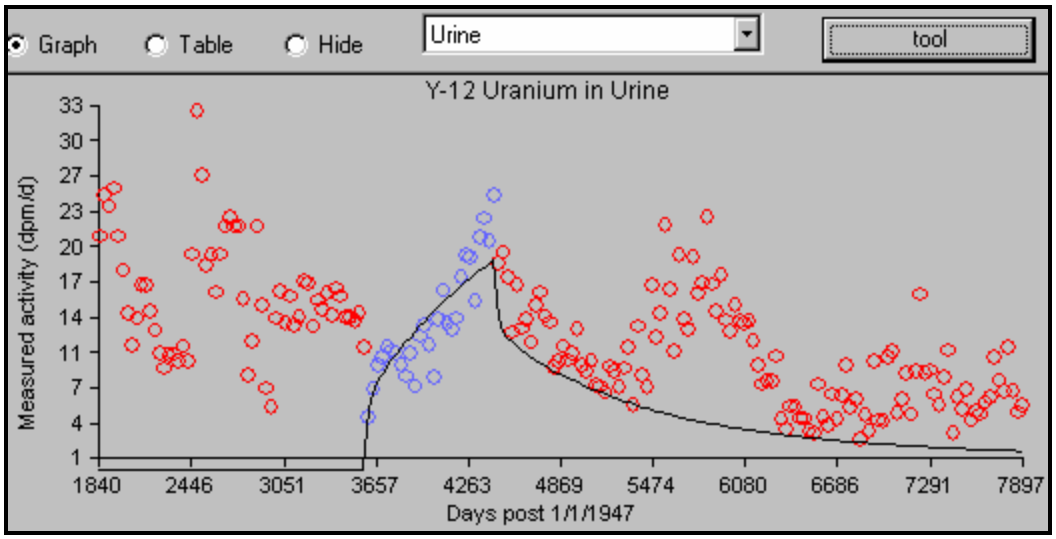


Figure A-14. Assumed uranium intake, 11/1/56 to 2/28/59, 50th-percentile results, type S.

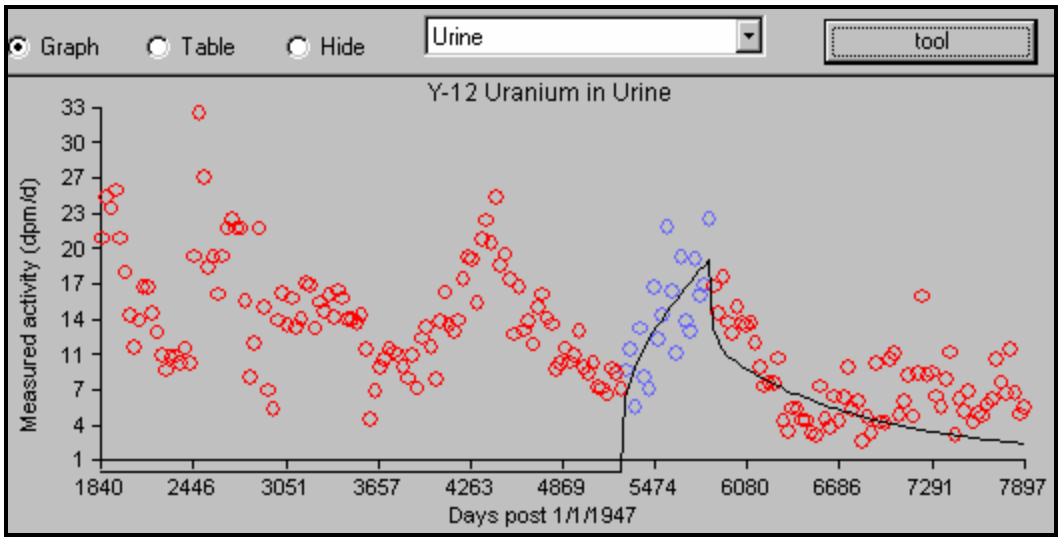


Figure A-15. Assumed uranium intake, 6/1/61 to 12/31/62, 50th-percentile results, type S.

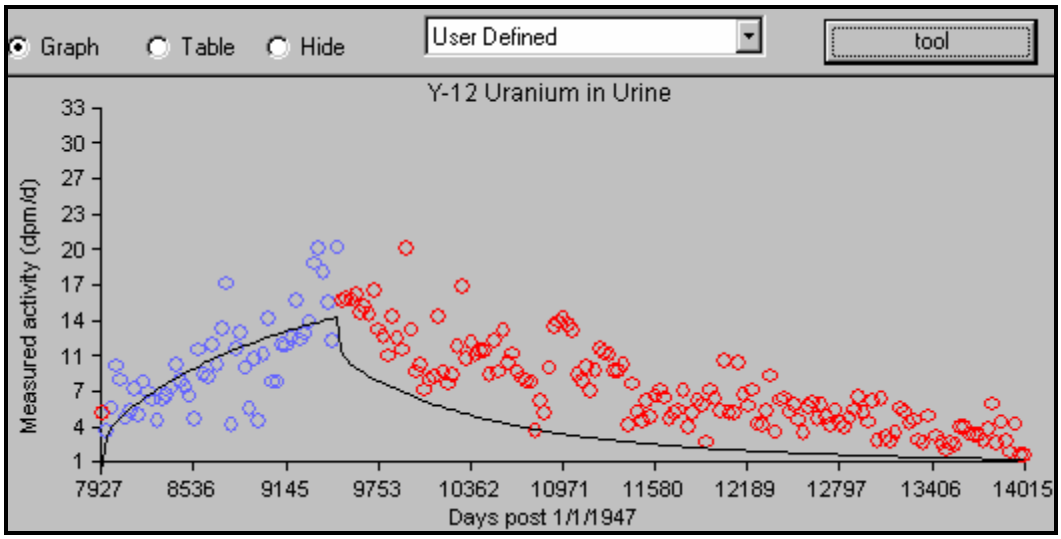


Figure A-16. Assumed uranium intake, 10/1/68 to 12/31/72, 50th-percentile results, type S.

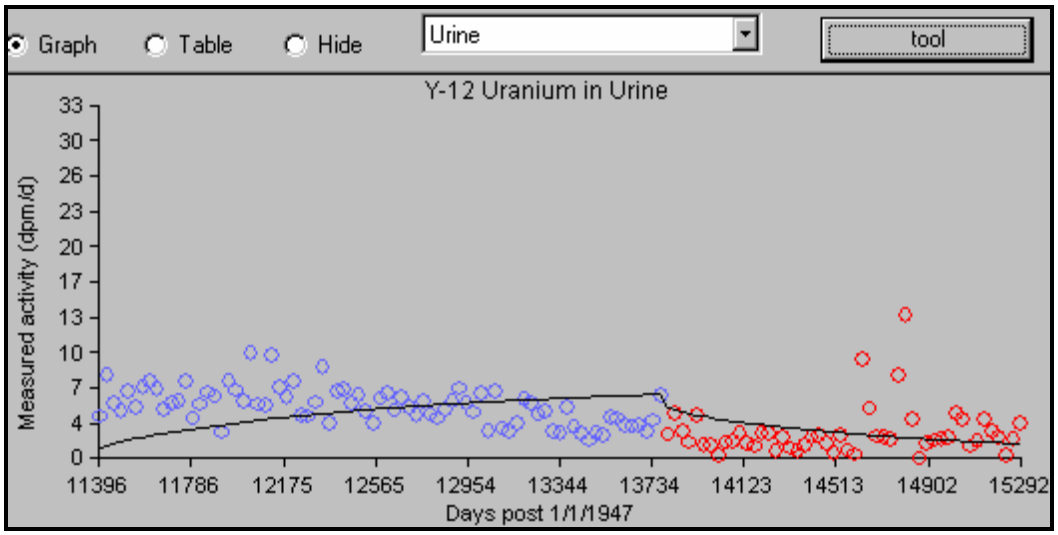


Figure A-17. Assumed uranium intake, 3/1/78 to 9/30/84, 50th-percentile results, type S.

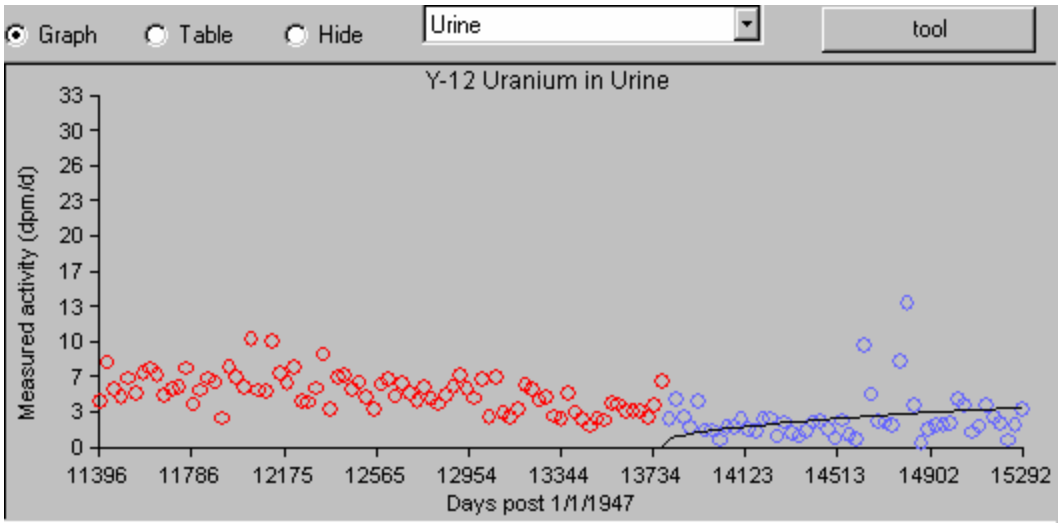


Figure A-18. Assumed uranium intake, 10/1/84 to 12/31/88, type S.

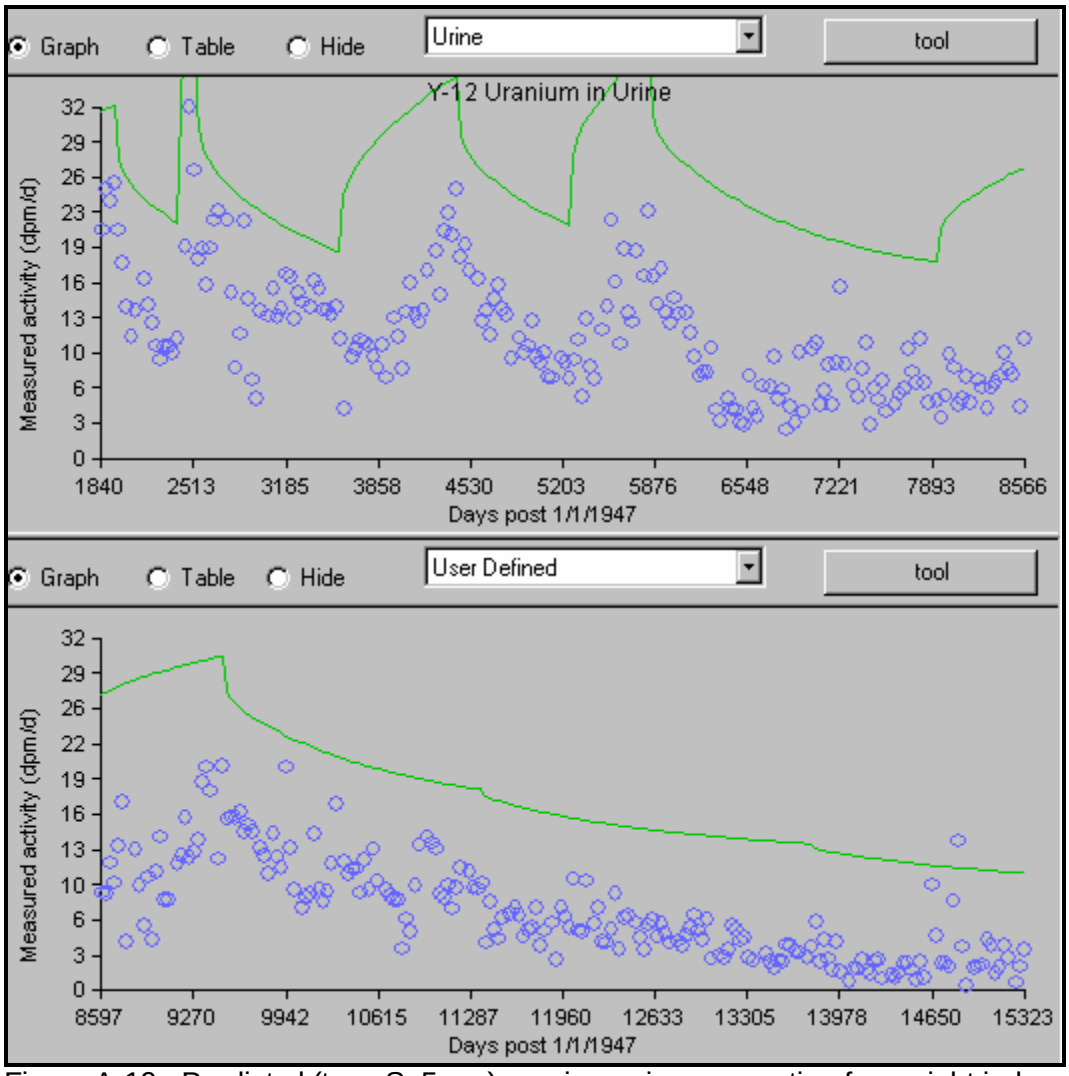


Figure A-19. Predicted (type S, 5 µm) uranium urinary excretion from eight independent intakes, 50th percentile, 1952-1988.

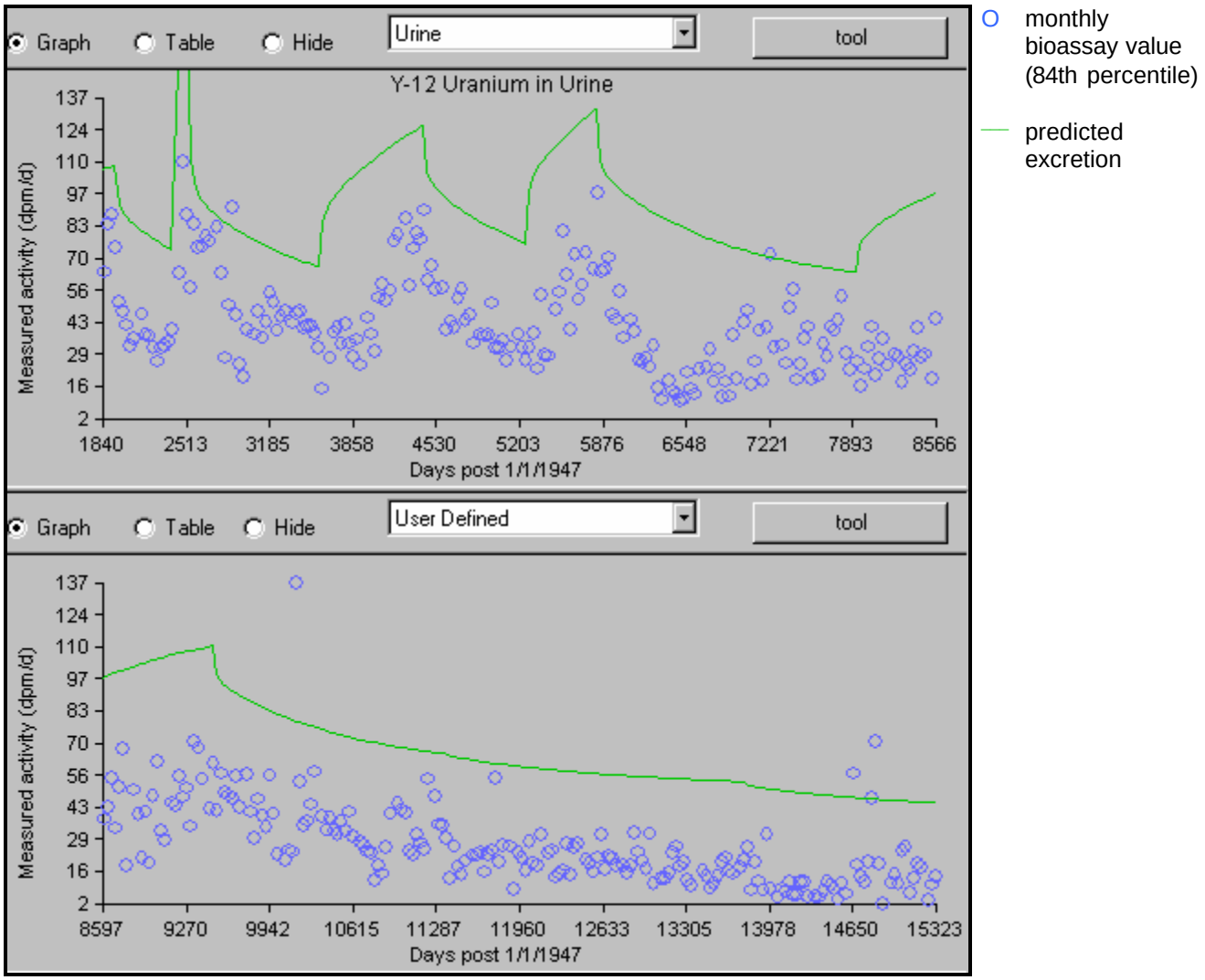


Figure A-20. Predicted (type S, 5 µm) uranium urinary excretion from eight independent intakes, 84th percentile, 1952-1988.

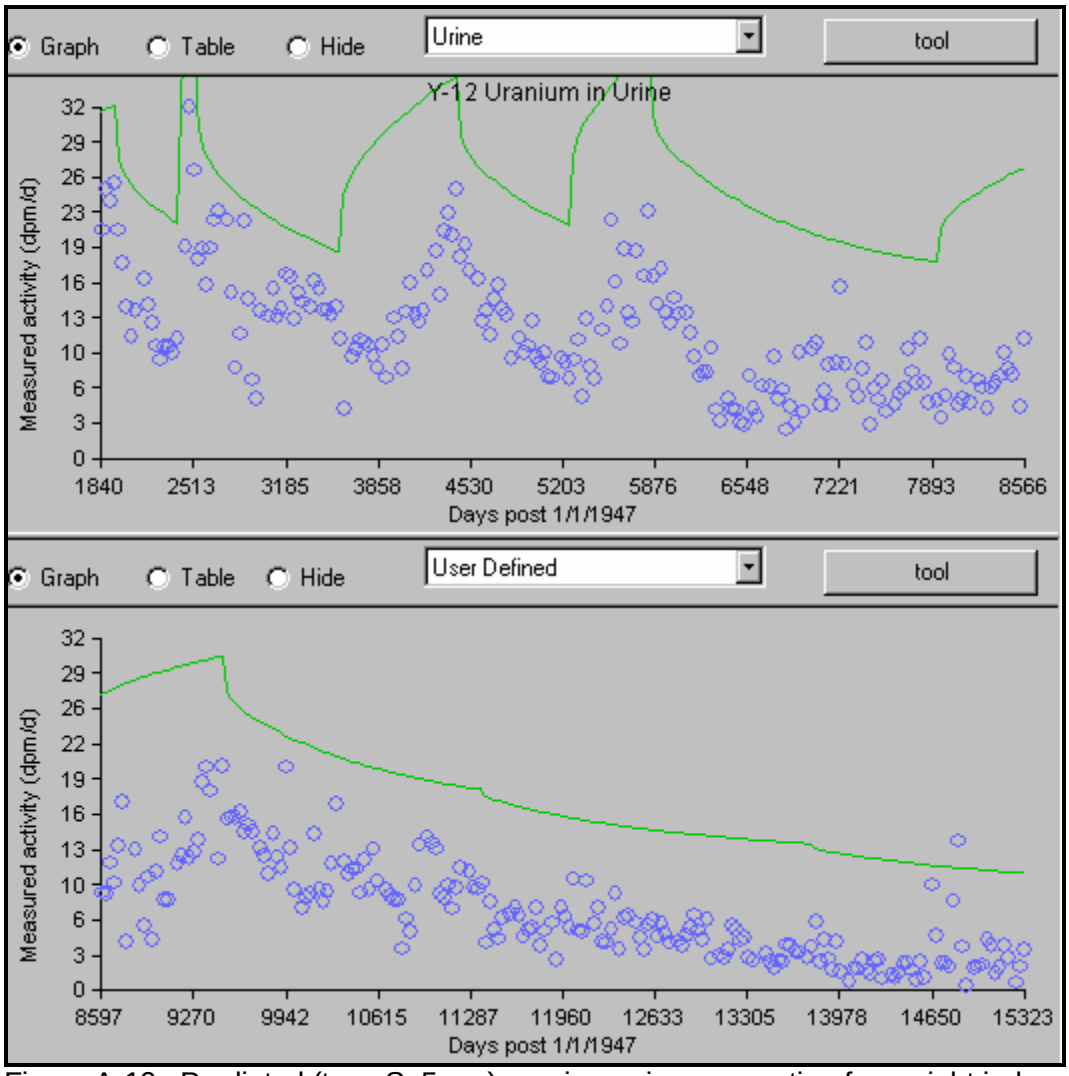


Figure A-19. Predicted (type S, 5 µm) uranium urinary excretion from eight independent intakes, 50th percentile, 1952-1988.

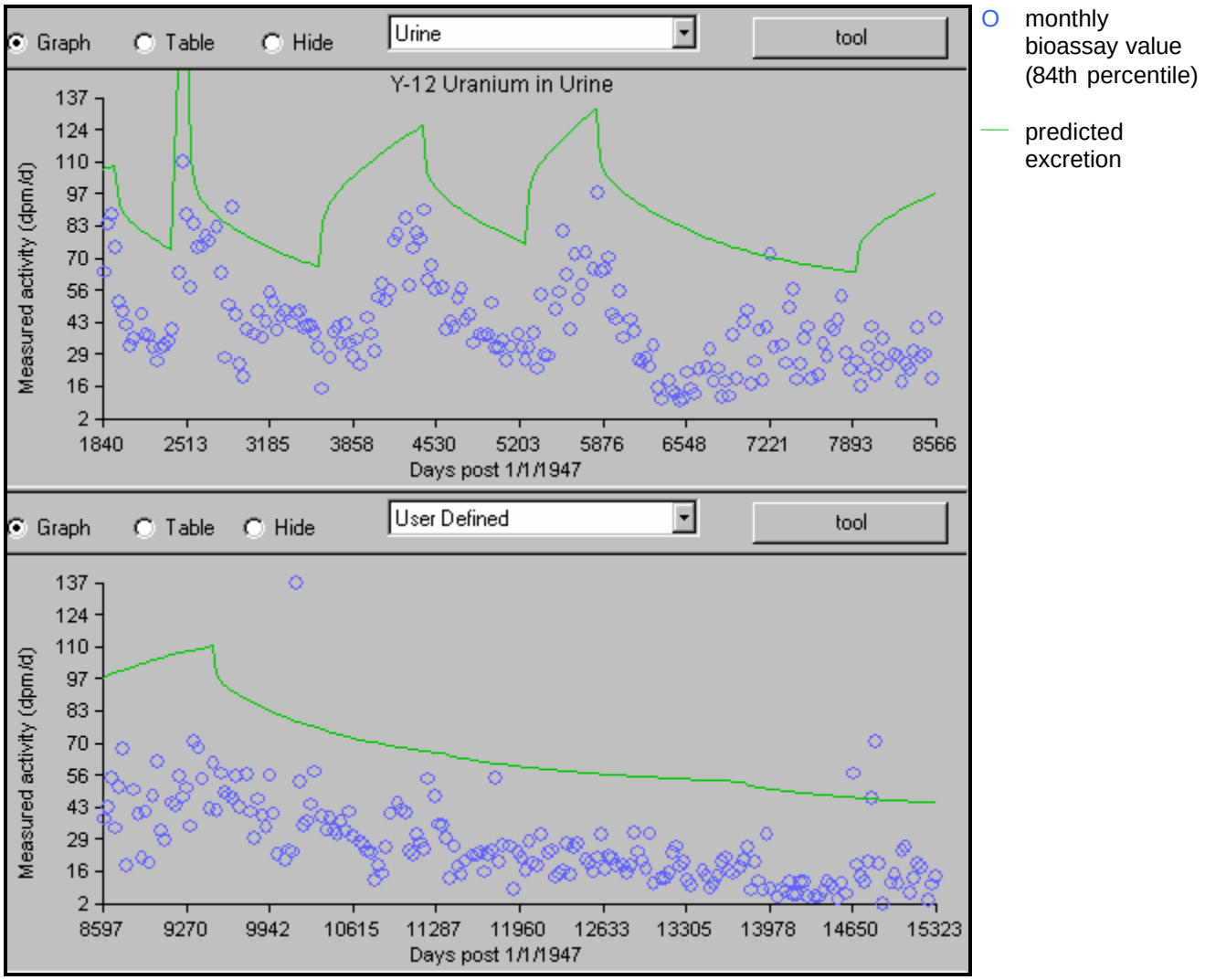


Figure A-20. Predicted (type S, 5 µm) uranium urinary excretion from eight independent intakes, 84th percentile, 1952-1988.